Journal of Archaeological Method and Theory, Vol. 5, No. 2, 1998

The Unitary Association Method of Relative Dating and Its Application to Archaeological Data

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The primary objective of relative dating techniques is to determine a reliable sequence of archaeological deposits. This task becomes more difficult whenever our research steps beyond individual sites to the study of intercommunity relationships because we need to develop some means of associating unconnected deposits in time. Radiocarbon dating, as a stand-alone method, cannot always be used to draw reliable correlations between sites. The relevance of archaeological dates, including absolute dates, relies ultimately on the determination of artifact or sample associations and their respective superpositional relationships. The Unitary Association Method of Relative Dating is an alternative to seriation methods that is less susceptible to spatial variation and offers analytical strengths needed for regional chronological analyses.

KEY WORDS: relative dating; geoarchaeology; classification; Unitary Association Method.

INTRODUCTION

The objectives of this paper are to introduce a new method of relative dating, to demonstrate its operational principles, and to evaluate its performance using archaeological data. The Unitary Association Method of Relative Dating (UAM) is an analytical procedure devised by the geologist, Jean Guex (1977, 1987, 1988, 1991), to correlate sedimentary beds at geological sites. The method is graph theoretic and employs deterministic techniques, such as those common in linear algebra, to manipulate data through logical steps, or algorithms (see Guex and Davaud, 1984; Savary and Guex, 1990, 1991).

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UAM builds on concepts and methods that many archaeologists use intuitively in the field. Guex's major contribution was to implement a series of mathematical procedures that allow systematic correlation of stratigraphic units by the associational and superpositional relationships of their contents. The method was originally intended to correlate stratigraphic units on the basis of their fossil content, but it can also be used to correlate archaeological strata on the basis of artifact content, provided that certain methodological concerns are addressed.

To date, the most popular technique for ordering artifacts or strata (using groups of artifacts) from two or more sites is seriation. The principles and assumptions underlying various seriation methods have been discussed at length elsewhere (Rouse, 1967; Dunnell, 1970; Cowgill, 1972; LeBlanc, 1975; Marquardt, 1978; Baxter, 1994; Duff, 1996) and are mentioned here only to clarify certain points of comparison.

One advantage of UAM over seriation techniques is that its results are not as susceptible to spatial variation in artifact assemblages. Consequently, its application is not constrained to specific localities containing similar artifact sequences or "traditions." Another advantage is that it is not necessary to assume that artifact styles change gradually over time or that the relative frequencies of these styles change monotonically (their popularity increases or decreases through time). These characteristics make it possible for UAM to order archaeological strata that contain stylistically unrelated assemblages.

The relative dating of archaeological strata is inseparable from the study of artifact classification and stratification. In effect, whenever a site's stratigraphic sequence is constructed, we have relatively dated those deposits. Yet when we attempt to correlate these deposits with those from another site, we must rely on the relationships of their artifactual contents, rather than stratigraphic principles. Thus, the correlation of strata between sites initially entails a study of site-formation processes at individual sites in order to determine their stratigraphic sequences. This is followed by constructing a regional artifact typology and placing the resultant types in their stratigraphic context. The superpositional and associational context of artifacts at individual sites is the contextual information used by UAM to correlate strata between sites.

In this paper I provide an overview of relative dating principles and assumptions and how they relate to the problem of correlating strata between sites, discuss the classification of artifacts and stratigraphy as they pertain to chronological analyses, provide a simple demonstration of UAM using three fictitious sites, and apply UAM to a case study of four sites in the southern Levant.

The introduction of any new method requires defining methodological terms and constructs. Consequently, it takes some time before the "nuts and bolts" of the method are explained. I ask the reader to bear with me because only by understanding the components of the method will its uses and limitations become clear.

The results of the analysis suggest that UAM is a useful chronological tool for archaeologists interested in regional studies or settlement patterns. However, the method, which is primarily deterministic, could possibly be improved by integrating probabilistic techniques.

RELATIVE DATES AND TIME PLACEMENT DATES

Relative dating methods are used to reconstruct a sequence of past events for either a single site or a group of sites by associating individual deposits with a specific artifact or a group of artifacts. The word "artifact" is used here to define any material expression of human cultural activity (Spaulding, 1971, p. 24) or, alternatively, anything that displays attributes resulting from human activity (Dunnell, 1971, p. 117; Stein, 1992, p. 80).

Changes in artifact types become chronological markers that can be used to identify time periods. Dates provided by these methods are often referred to as "relative placement dates" (Dean, 1978, p. 525; Smiley, 1955). These dates are ordinal-scale measures: the value of any date can be "greater than" or "less than" another, but the duration of any event and the magnitude of the interval separating events are unknown. Relative dates are generally distinguished from "absolute" dates, such as those from radiocarbon dating or thermoluminescence (TL) dating, but Dean (1978), borrowing from the work of Smiley (1955), reserves the term "absolute placement date" for calendrical dates and uses "time placement dates" to refer to dates that represent probabilistic time intervals. This terminology is more specific. For example, a calibrated radiocarbon date is a time placement date. A date of 3000 ± 100 years BC derived from wood charcoal describes a time interval in which the actual date of the event (the time of death for the wood fiber) has a 68% chance of falling between 3100 and 2900 BC.

Time placement dates, especially those measured on the radiocarbon time scale, are often used inappropriately as a relative dating technique. This is usually accomplished by ordering radiocarbon dates by their means, a practice that oversimplifies the meaning of radiocarbon results and ignores the multimodal distributions of calibrated dates and the size of standard errors (Bowman, 1990, p. 57). Procedures for comparing and combining radiocarbon dates are illustrated by Ward and Wilson (1978) and other, more effective, approaches have been suggested (e.g., Buck *et al.*, 1991). The term "relative dating" generally does not apply to the ordering of time placement dates.

Radiocarbon dates are often accepted uncritically as a means of correlating strata between sites, but it is important to note several problems associated with this practice. Apart from problems related to sample contamination and to variations in the time spans represented by different samples (Bowman, 1990, p. 15), a single ^{14}C date derived from a sample in any one context is seldom reliable, and even when several samples are dated, the results cannot always be reliably combined. While it is not the purpose of this paper to discuss radiocarbon dating at length, it is incumbent on archaeologists to understand the limitations of radiocarbon dating in the correlation of deposits.

To determine the contemporaneity of sites using radiocarbon dates, several steps must be followed. First, it must be determined that the samples have a similar time span. A sample taken from a 300-year-old oak is not suitable for comparison to short-lived bone material. Second, we need to determine the likelihood that the two dates are from the same population of dates; that is, the probability that they were drawn from material of the same radiocarbon age. Their probability distributions may not overlap enough to be considered viable candidates. This likelihood can be assessed statistically using a chi-square test (Bowman, 1990, p. 58). If the dates can be combined, then the means and the error terms of all compatible dates must be pooled (Orton, 1980, p. 93). For example, if there are two sites and both are dated to 3000 ± 100 years BP (uncalibrated), they would have a pooled mean of 3000 BP and a pooled error of $\sqrt{100^2 + 100^2} = 140$ yielding a 1σ range of 280 years. In practical terms, there is a 68% chance that the *true dates for both sites* fall in the range of 3140 and 2860 BP. If more certainty is required, the range can be increased to 2σ. In this case, there is a 95% probability that the true dates for each site fall between 3280 to 2720 bp, a range of 560 years. Therefore, if the dates are accurate, it is possible for two occupation levels with the same mean date and the same associated error to be as much as 560 radiocarbon years apart. The calibrated dates could differ even more.

New radiocarbon techniques (e.g., accelerator mass spectrometer) have improved the precision of radiocarbon dates (i.e., reduced standard errors) but improved precision does not mean improved accuracy. For example, a radiocarbon sample may produce a date of 3000 ± 10 years BP, which is very precise, but if the true date of the sample is 3500 BP, then it is not very accurate. The calibration of radiocarbon dates using dendrochronology improves the accuracy of dates but not of radiocarbon test results, and calibration cannot account for the selection of inappropriate samples. While there can be little doubt as to the value of radiocarbon dating to archaeology, the dates and the contexts of radiocarbon samples need careful consideration before drawing any correlations.

The principles of relative dating are germane to all dating techniques because, regardless of whether relative, interval, or absolute dating methods are used, archaeologists cannot escape the need to determine both the sequence of deposits and the reliability of artifact contexts. Dates derived from samples (the dated event) must be related, by way of bridging arguments, to other archaeological materials (the target events) believed to be associated with the sample (Dean, 1978). For radiocarbon dates, we would need to judge the association of the carbon sample to artifacts of interest, and for TL dates, we may need to know how dated pottery is associated with a particular building or some faunal material.

Determining artifact associations is key to many archaeological analyses, and UAM is no exception in this regard. In fact, defining artifact associations over time is a critical aspect of the method, and one that brings with it a number of problems common to the discipline. Not all contexts are the same and finding artifacts in specific spatial associations does not necessarily mean that these artifacts were chronologically associated in any way. The degree of confidence we place in any temporal association of artifacts is usually greater when the artifacts are found in a closed context, such as a single burial, than when they occur in a loosely defined amalgam of deposits, generally termed a stratum or a layer. Ultimately, determining the sequence of deposits and the confidence of associations is a matter entirely in the hands of the field archaeologist, and the results of any chronological analysis depend on the quality of these data.

ARTIFACTS, STRATIGRAPHY, AND TIME

The primary data of UAM are artifact classes and stratigraphic units. Stratigraphic units, like artifacts, are not all the same and have their own system of classification. Much of the confusion surrounding relative dating and the creation of relative time units in archaeology (such as components, phases, and periods) stems from confounding artifacts, geography, and time (Stein, 1992, p. 75). Some archaeologists freely admit that the stratigraphy at their sites was determined on the basis of artifact content alone and not on stratigraphic principles (e.g., Baruch, 1987, p. 276; Garfinkel, 1992, p. 19). In other situations, the provenience of artifacts is not reported, making it impossible to reevaluate the excavators' criteria for grouping different deposits into particular phases or periods. Because so few contradictions in the sequence of types are ever reported, it is difficult to escape the impression that contexts are often grouped on the basis of types alone rather than on a study of stratification. The inevitable result of this practice is that any interpretation of the sequence of events becomes tautological. What must be examined is the empirical evidence on which these *a priori* assumptions are based.

Artifacts

Artifact Classes

The strengths and weakness of UAM can best be appreciated through an understanding of what a "class" represents and how different classifications affect the results of analysis. Dunnell's (1971, p. 47) first axiom of classification is that all classification is arbitrary. It is difficult to escape the fact that the individual who classifies an object is the one who determines which criteria are relevant to analysis. Rarely, in any discipline, is consensus on matters of classification ever reached. Consequently, the subjective nature of artifact classification can be an impediment to regional studies and to chronological analyses, both of which are based on comparative methods.

A taxon is any class of artifact or fossil that has been created by means of systematics (a system of classification). The units of analysis are not the real objects themselves but the classes or types that we have defined on the basis of specific criteria. Archaeologists working within a particular region may or may not agree on the general types of artifacts or on the criteria used to define a type (e.g., see Plog, 1978, p. 159).

Artifact classifications are created to serve various purposes (Hill and Evans, 1972, p. 244; Klejn, 1982, p. 51; Adams and Adams, 1991, p. 157). Our purpose is instrumental (Adams and Adams, 1991, p. 158), meaning that we want the classified material to tell us something about the date of a site rather than about the material itself, and it is comparative, because we rely on similar classes of materials to draw correlations. The ideal attributes in our system of classification would have a short duration, be widely dispersed in a short period of time, and would preserve well in a number of different depositional environments (Lemon, 1990, p. 155). In addition, a classification system is needed that can account for spatial variation in assemblages and time lags in artifact appearances.

In seriation analyses, it is often assumed that the use of attributes as data will yield better results than types (groups of attributes) because important information can be lost or subsumed within a type (LeBlanc, 1975). However, in a contrary finding, Duff (1996) reanalyzed LeBlanc's material from Pueblo de los Muertos and found that the use of types instead of attributes yielded similar results. The reason for this is that, whether types or attributes are used, both kinds of data are qualified, and as units of analysis, both are measured on a nominal scale. They are the same kinds of data. There is no reason to suggest that a particular attribute is any more chronologically significant than a selected *group* of attributes (a type). It is primarily the nature of the data and how it relates to the chronological problem at hand that determine the success of analysis (Rouse, 1967, p. 159). The decision to use either individual attributes or types in a chronological analysis must be left to the discretion of the researcher and depends to a great extent on a working knowledge of attribute variations over time and space for any regional assemblage.

Homology and Homeomorphy

Stratigraphic correlations are based on the assumption that similar artifacts are closely related in time. Implicit in this assumption is that similar artifacts are related not only in time but also in terms of their cultural and technological context. *Homologous* artifacts are "genetically" related to their predecessors but are not necessarily the same in all aspects. Their form and style are an outgrowth of previous forms and styles, usually combined with innovative characteristics of either an autochthonous or foreign origin. The term "homology" carries an explicitly evolutionary view of artifact development. Two artifacts that are homologous would be expected to have more attributes in common that those that are not. When homologous artifacts occur at two or more sites, some degree of cultural interaction or cultural continuity is assumed.

In other cases, similar artifact classes are not related, either in time or culturally. *Homeomorphous* artifacts appear to be similar but are unrelated in origin. They can occur when an artifact is replicated at a later date, independently invented, or curated or when factors of chance or function create a similar association of attributes. Including homeomorphs in an analysis will adversely affect correlations.

Spatial Variation and Artifact Diachroneity

Spatial variation in artifact assemblages makes correlation between strata difficult because, as the distance between any two sites increases, it is less likely they will have any artifact types or attributes in common (Klimek, 1935; Milke, 1949; Clarke, 1968; Hodder, 1978; DeBoer, 1993). The many causes of spatial variation have been discussed at length elsewhere and are not treated here (cf. Plog, 1978, 1980; Rogers, 1995; Leeuw and Torrence, 1989; Basalla, 1990; Conkey and Hastorf, 1990; Schortman and Urban, 1992; DeBoer, 1993).

Archaeologically, there are two aspects to spatial variation; one is synchronic and the other diachronic. Synchronic spatial variation is observed as a snapshot in time. It is the ideal state representing a true picture of artifact distributions over a particular landscape for any instance. As one travels from one point to another, observed changes in material culture are generally attributed to differences in either local traditions or historical trajectories. Diachronic spatial variation occurs when landscapes from different periods of time are grouped and treated as a single period. This is the state most often observed archaeologically. Events are conflated and spatial variation is confounded with temporal variation. Diachronic spatial variation occurs because of the limitations of chronological methods, and each method affects this variation in different ways. For example, it is possible for the diachronic spatial variation of the previously discussed radiocarbon samples to equal the sum of all spatial variation over a 560 year period.

Relative dating methods, because they assume similar artifacts to be contemporary, are prone to this type of error if artifacts are *diachronous* (Guex, 1991, p. 102). Diachronous artifacts are those that appear first at one community and, later, at another. The term "diachronous" rather than "diachronic" is used to describe boundary effects that are time-transgressive. The effect of artifact diachroneity, or time lags, on the correlation of strata was noted by Deetz and Dethlefsen (1965), who referred to it as the Doppler effect.

As the magnitude of diachroneity (i.e., the interval between the first appearance at one site and the first appearance at another) increases, correlations become less precise. Practically speaking, most ideas and artifacts are diachronous to some degree, but an artifact that took even 10 years to spread throughout a region will have a negligible effect on the correlation of strata. The point at which artifact diachroneity becomes a problem depends on the chronological resolution expected for any particular analysis. Ideally, the period over which time lags occur should be no greater than the period of occupation being investigated (Read, 1979, p. 91).

The distinction between synchronic and diachronic spatial variation is important because seriation techniques are affected by both the differences in cultural traditions and the diachroneity of artifacts. UAM, on the other hand, is unaffected by variations in cultural traditions and can isolate diachronous artifacts to improve correlations.

Artifact Intervals and Associations

The length of time during which artifacts of a particular class are made and used affects any method of stratigraphic correlation that assumes that similar artifacts are contemporary. In geology, when we speak of the "existence" of a past life form, we refer to the total life span for that species, from the moment of its first appearance to its last. This is called its *existence interval.* When the term "existence" is used for artifacts, it cannot, of course, have the same meaning. Ideally, the term refers to the use-life of an artifact, or the time that it remained in a systemic context. On a practical level, however, the term refers to an interval of time that is based on an artifact's archaeological context, which may or may not be systemic. Clearly, existence intervals can be affected by the appearance of undetected homeomorphs, by the ways in which an artifact is reused, intrusions, or when site disturbances go unnoticed (cf. Schiffer, 1996, pp. 28, 317). Assuming that these depositional factors have been accounted for, the existence interval of an artifact is defined as the time interval between its first known stratigraphic appearance and its last known stratigraphic appearance.

When the existence intervals of two or more artifact types overlap, the types are said to share a *concurrent interval.* In other words, if artifact A is found in strata 1 to 4, and artifact B is found in strata 3 to 5, then they are concurrent for the interval represented by strata 3 and 4. In terms of set theory, the shared interval is the intersection of the two existence intervals. Thus, if artifacts share the same concurrent interval, it is assumed they are associated for that interval. The term "association" has been used in a number of different ways to describe the relational dimension of artifacts. In this paper, the term is used to describe chronological associations, not spatial or statistical ones. For example, the word is not used to suggest that two or more artifacts are statistically correlated in any way, although they may be. Nor should overlapping existence intervals be confused with the concept of "overlapping assemblages" (Childe, 1952, p. 47; Willey and Phillips, 1958, p. 33) or "association groups" (Hodder and Orton, 1976, p. 199). These are spatial, not chronological, terms.

The association of two or more artifacts does not imply that they were always concurrent. If one artifact has an existence interval of 300 years and another found in association with it has an interval of 50 years, then there was a period of at least 250 years when the two did not cooccur. Therefore, if two artifacts are found together, we know that the time span of this association can be no greater than the minimum existence interval, which, in our example, would be 50 years. If a third artifact is added to the set of artifacts, it may be possible to further reduce the concurrent interval. While it is often impossible to know an artifact's true existence interval, as a general rule, the chances of encountering a smaller concurrent interval increase as the number of associated artifacts increases. This fact gives strength to chronological arguments based on the cross-dating of two or more associated artifacts (Childe, 1956, p. 32; Schiffer 1996, p. 317).

Stratigraphic Units of Analysis

In addition to artifact classes, stratigraphic units and their relationships form essential components of UAM. The basis of most chronological frameworks, regardless of the dating method, is a comprehensive study of site stratification (Butzer, 1987, p. 71; Harris, 1989, p. 109; Stein, 1992, p. 71).

Many of the stratigraphic terms and definitions used here are taken from Stein (1992) who, on the basis of the *North American Stratigraphic Code* (NACSN, 1983), has adopted and interpreted certain aspects of stratigraphic nomenclature for the purposes of archaeological study. Stein suggests that archaeological layers be described, divided, and interpreted first as lithostratigraphic units, then as ethnostratigraphic units (defined by artifact content), and finally as chronostratigraphic units (grouped by artifact content). There are good methodological reasons for following this procedural sequence, as will become clear.

Lithostratigraphy

A lithostratigraphic unit is defined, distinguished, and delimited on the basis of its physical characteristics. It is stratified and usually conforms to the law of superposition (NACSN, 1983, p. 856). In the field, archaeologists differentiate deposits using lithological criteria, such as sediment or soil color and composition. For archaeological purposes, a *deposit* is generally defined as the smallest lithostratigraphic unit excavated at an archaeological site and can be further defined as any three-dimensional volume of material that is spatially discrete, is distinguishable on the basis of observable physical properties (Schiffer, 1996, p. 265; Stein, 1987, p. 339), and results from a single depositional episode.

Often it is desirable to group deposits into larger lithological units. Stein (1992, p. 78) suggests the use of the term "layer" for these grouped deposits, but the term can generally be used interchangeably with "stratum." Layers are synthetic units, lithologically defined, that should be mappable across the entire site. This definition of layer is useful, but not all archaeological deposits are easily grouped into larger units on lithological criteria alone, especially in the geological sense of the term. However, archaeological analyses have the added advantage of correlating site deposits across an area by using construction and collapse events as stratigraphic boundaries, particularly where substantial architecture existed (cf. Blackham, 1998).

Biostratigraphy and Ethnostratigraphy

In geology, a biostratigraphic unit is a body of rock defined or characterized by its fossil content (NACSN, 1983, p. 863). Stein (1992, p. 72) applies the concept to deposits that are defined by their artifact content and calls them *ethnostratigraphic units.* While this term implies that stratigraphic units are defined by their cultural materials, it may also have other, unwanted connotations. The prefix "ethno" generally refers to a people, or a single cultural group, but at any point in time, a particular site or region may have been comprised of several different cultures or ethnic groups. To avoid a proliferation of terms, the prefix "ethno" is retained, but its use is not meant to imply that a stratigraphic unit corresponds to any single ethnic group.

Lithostratigraphic units are defined at their spatial boundaries by their physical characteristics, and in turn, these same boundaries delimit the artifact content of that unit. Alternatively, an ethnostratigraphic unit is defined by these contents, but the two terms do not necessarily refer to the same stratigraphic unit. For example, if two or more lithostratigraphic units have the same contents, they belong to a single ethnostratigraphic unit.

Chronostratigraphy

When stratigraphic units are defined at their boundaries by the variable of time, they become *chronostratigraphic units.* Theoretically, chronostratigraphic units are regional units that can be lithologically defined in their upper and lower limits by isochronic horizons. An isochronic horizon defines a regional landscape for a given period of time. Isochronic horizons are difficult to identify except, for example, in cases where a regional covering of volcanic ash or eolian deposits can be recognized. A chronostratigraphic unit is described in the same manner as "layer," except that it is regional in scope.

A *chronozone* is a chronostratigraphic unit. It defines the smallest regional layer and is usually of a short interval, but it can span any period of time depending on its purpose. Stein (1992, p. 85) calls chronozones based on artifactual data *ethnochronozones.* The relationship between chronostratigraphic units and ethnostratigraphic units is a close one because the latter are often used to define the former and the distinction between the two is not always clear. Lemon (1990, p. 210) claims that, on a practical level, biozones (ethnozones) are chronozones and that the only difference between the two is one of interpretation and description.

It should be remembered, however, that an ethnostratigraphic unit can be diachronous on its upper and lower limits because of spatial variation in assemblages. In contrast, a chronostratigraphic unit is ideally isochronic at its boundaries. Ultimately, therefore, the identification of chronostratigraphic units remains the primary objective of chronological analyses. UAM constructs ethnochronozones using interval ethnozones, which are explained below.

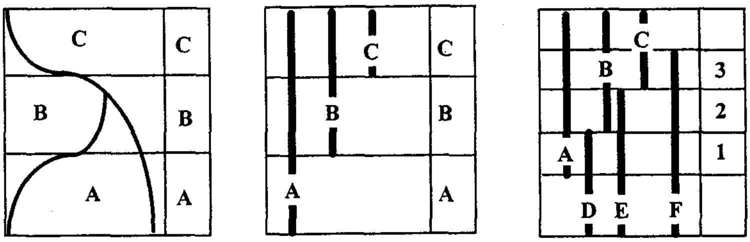
Ethnozones

The fundamental unit of a biostratigraphic classification is a *biozone.* These are bodies of sediments that are defined by the presence, absence, or relative abundance of a certain taxon or assemblage of taxa (Lemon, 1990, p. 204). Stein (1992, p. 80) proposes the use of the term *ethnozone,* of which there are three principal kinds: assemblage zones, abundance zones, and interval zones (NACSN, 1983, p. 863; Guex, 1991 p. 1; Stein, 1992, p. 80). An ethnozone is used as a means of defining the limits of an ethnostratigraphic unit.

Assemblage Zone. An assemblage zone is characterized by the association of three or more artifact types. It can be geographically (horizontally) or stratigraphically (vertically) restricted, depending on the artifacts that define it. The use of assemblage zones is a popular method in archaeology for identifying layers and is roughly analogous to a phase or horizon (Willey and Phillips, 1958, pp. 22, 33).

Abundance Zone. An abundance zone (also called an acme zone) is characterized by quantitatively distinct maxima of relative abundance for one or more artifact types. What this means is that a zone can be identified by the most common artifacts, usually established on the basis of relative frequencies. Kroeber (1916) used this technique to identify different occupations in the Zuñi region of New Mexico and it remains a popular means for defining occupation levels.

Interval Zone. Two interval zones are of interest here. One is called a range zone, which includes all deposits between the first and the last known appearance of a single artifact type and is equivalent to an existence interval. The other is called the concurrent range zone, which is defined by the stratigraphic overlap of two or more artifact ranges and is referred to here as a concurrent interval. Both range zones and concurrent range zones have found currency in archaeology. Childe (1925) used concurrent range zones, which he later called "chorological co-ordinates" (1956, p. 15), in his analysis of European prehistory. Guex's (1991) method constructs concurrent range zones that contain *unique associations* of taxa (Fig. 1). He calls these "discrete zones." UAM uses discrete zones to construct interval ethnozones.



Abundance Zones Range Zones Concurrent Range Zones

Fig. 1. Three methods of defining ethnozones. Assemblage zones are not shown (after Guex, 1991, Fig. 1.1).

Each method of zone construction has its own strengths and weaknesses. The use of range zones and concurrent range zones (interval ethnozones) is generally encouraged for the correlation of stratigraphic units because they can be used to identify unique sets of taxa. Strictly speaking, a concurrent range zone is an assemblage zone, but one that is explicitly defined by overlapping existence intervals. Abundance zones, although they can be useful for local correlations, are generally not used by geologists because many factors can affect the relative frequencies of taxa from location to location. This is true for archaeological data as well, and the results depend to a great degree on the effects of differential site functions (e.g., activity areas), differential deposition, site disturbances, differential preservation, and differential recovery, all of which serve to affect artifact counts and relative frequencies.

In summary, artifact associations are first determined by the lithostratigraphic units (deposits) that contain them, then, on the basis of these associations, ethnozones are used to define ethnostratigraphic units. Ethnozones can be constructed in several different ways, depending on how the data are organized. UAM constructs ethnozones by using concurrent range zones. From Guex's discussion and his classification of terms, it is evident that he takes the same view as Lemon's, that is, that biozones (ethnozones) and chronozones are much the same.

CORRELATION PROBLEMS

Attempts to correlate strata face a number of practical problems, the most common of which are as follows.

Classification. The classification of artifacts is fundamental to ethnostratigraphy and presents one of the most difficult challenges. Classifications need to be systematically constructed and internally consistent (Dunnell, 1971, p. 60).

Artifact Associations. Artifact associations must be lithologically defined. Correlating stratigraphy on the basis of assumed associations can be misleading and often results in tautological arguments.

Common Artifacts. Within any geographic region of study, each site must have some artifact types in common with at least one other site if they are to be successfully correlated. The degree of confidence in any correlation of strata is a function of the number of common types they contain.

Spatial Variation. Synchronic and diachronic spatial variations affect our ability to draw accurate correlations between distant locales.

Depositional and Postdepositional Factors. Any number of site-disturbance processes can affect the archaeological context of artifacts and produce errors of association and superposition.

UAM AND SERIATION

The primary assumption of relative dating methods is that similar artifacts are more closely related in time. This assumption is general in nature and is not always well founded. Similarities in artifacts can be homologous, implying a thread of continuity in style or formal characteristics. Links of this kind are intergenerational and represent the transmission of knowledge over time. Similarities in artifacts can also be cross-cultural or even pandemic and represent a relatively synchronic transmission of knowledge over geographic space.

Seriation orders groups of artifacts on the basis of homologous similarities, while UAM orders these same groups on the basis of artifact superposition. UAM does, however, assume that existence intervals represent periods of typological continuity. If any two artifacts were widely separated in time and belong to the same artifact class, then it is implied that a homologous link exists between them and that no perceptible change in that class can be recognized for the period of time designated by the interval. The different techniques each method has for ordering groups of artifact types dictate their respective strengths and weaknesses.

Seriation methods can, for the most part, ignore the context of finds. For example, if we are interested in the chronological development of a specific artifact type, such as Dethlefsen and Deetz's (1966) gravestones, no stratigraphic sequence or association of artifacts is required because the gravestones can be ordered by their stylistic similarities alone. Clearly, the method is advantageous in situations where the context of finds is doubtful.

Site 1	Site 2	Site 3
{A, B, C, D}	{C, D, E, F}	{C, E, F, G}

Intersection of sets = {C}

Union of sets = {A, B, C, D, E, F, G}

Fig. 2. Sets are combined differently in seriation and UAM. Letters in sets represent artifacts.

Seriation orders a single class of artifact on the presence of specific attributes, such as a certain kind of handle or decoration on a pot, and it orders groups of artifacts in a similar manner except, in these cases, we treat the group as an object to be seriated and the individual artifact classes are the attributes of the group. This is the basis of seriation techniques used to order and correlate the strata of two or more sites. The problem with seriation methods when ordering and correlating groups of artifacts becomes apparent when regional analyses are attempted because seriation methods are particularly susceptible to the effects of spatial variation, as well as other factors (see Marquardt, 1978, pp. 445-452).

UAM, like seriation methods, initially groups artifacts by lithostratigraphic units. It also assumes that similar artifacts are more closely related in time but, rather than using coefficients of similarity to order groups of artifacts, it uses the superpositional relationships between sets of artifacts for this purpose. Consequently, the results are not affected by spatial variations in the same way. For example, assume that sites A, B, and C were contemporaneous. Site A has no artifacts in common with site C but site B has artifacts in common with both site A and site C. In this case, spatial variation exists between assemblages. Seriation methods would create a sequence of A–B–C or C–B–A, whereas UAM, using superpositional data, could determine that all sites were contemporary for that interval. Its spatial limitation is that, without site B, no correlation could be drawn between site A and site C. This same limitation applies to seriation methods.

Spatial variation affects seriation and UAM differently primarily because of the way in which each method treats sets of artifacts. In terms of set theory, seriation methods rely on the intersection of sets to draw parallels whereas UAM uses the union of sets. For example, imagine that we have three sites with four artifacts each (Fig. 2). These sites have only one artifact in common {C}. This artifact represents the intersection of all three sets of artifacts and seriation methods must draw correlations *between all* *sites* on the basis of this single artifact. Alternatively, UAM, by the application of transitive and associative principles, determines that the artifacts in all three sets are associated and creates a maximal set that includes all contemporary elements {A, B, C, D, E, F, G}. The smaller sets of artifacts present at each site form subsets of the maximal set and are correlated on this basis. As we encompass a greater area, the number of elements in a union of sets generally increases, whereas the number of elements resulting from the intersection of artifact sets decreases until, eventually, there are no artifacts in common among sites.

While UAM is relatively unaffected by synchronic spatial variation (see above), it is affected by artifact diachroneity. The advantage of UAM over seriation is that diachronous artifact types can be identified and isolated in order to improve correlations. The identification of diachronous types is also useful to trace the movement of specific artifacts from one community to the next.

Like any method, UAM has its limitations. The method is not useful for sites in which superpositions and associations are unknown. It is possible, however, to integrate unstratified, or single-period, sites into any analysis that includes stratified sites, provided that these sites have some artifacts in common with the stratified sites.

UAM works best when all strata are of short, but not necessarily equal, duration. Dunnell (1970, p. 312) suggests that all units (i.e., groups of artifacts) included in a seriation should be of comparable duration so as not to affect the distribution of the classified objects used to create the ordering. This topic relates to the previous discussion of diachronic spatial variation. For UAM, the most important point is that, when the defining lithological unit represents a greater period of time, so will the group of artifacts it contains. This will create unwanted associations that result in a loss of chronological resolution. For example, if a unit spans 300 years and we group its contents as a single ethnostratigraphic unit, then we are assuming that all artifacts contained are contemporary. In these situations, and where there are grounds for doing so, it is best to create arbitrary stratigraphic units within the larger lithostratigraphic unit.

A DEMONSTRATION OF THE METHOD

UAM uses the presence or absence of artifacts as data and performs its mathematical operations using incidence matrices. There have been several discussions concerning the relative merits of presence/absence data and abundance data in constructing relative chronologies (Dempsey and Baumhoff, 1963, p. 499; Hole and Shaw, 1967, p. 78; Marquardt, 1978, p. 418; Baxter, 1994, p. 38). The point most often made against presence/absence data is that the results are

SITE 1

Layer	Artifact										Real Associations
	1	2	3	4	5	6	7	8	9	10	
5	1	1						1			{1 2 8}
4				1	1			0			{4 5}
3							1	1			{7 8}
2							0		1	1	{9 10}
1							1		1		{7 9}

Fig. 3. Real associations of artifacts are those actually observed during excavation.

highly susceptible to artifact intrusions that may result from site disturbances, whereas abundance data will tend to mask these effects. The results obtained with abundance data, however, will often reflect only what is true for a very localized sequence and may not be applicable to the whole site, let alone a region. This is particularly the case if the site is large and spatially organized, and the sample size is small. Furthermore, unstandardized abundance data tend to obscure the importance of rare items that may be unique to specific time periods. With either type of data, the effects of differential deposition, differential preservation, site disturbance, differential recovery, and the misclassification of artifacts will be problematic.

UAM is based on relatively simple mathematical principles but can be computationally complex when there is a large number of layers and artifacts. For the analysis performed here, a computer program called *Biograph: Version 2.02*[2] was used (Savary and Guex, 1990, 1991). The program numbers strata from the bottom up. I have retained this format in the following demonstration so that it can serve as a reference for those learning to use the program.

The description of analytical method given below has been greatly simplified, perhaps oversimplified on some points. The objective is to provide a clear and elementary sequence of steps that will facilitate understanding of the process. In the last part of this paper, UAM is applied to an actual case study. Throughout, I have attempted to situate the method within an archaeological framework. For the purposes of demonstration, three fictitious sites have been created and are used as an heuristic device (Figs. 3 and 4); the objective of the exercise is to correlate the layers of these sites.

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[2] *Biograph: Version 2.02* is DOS based. The program is available from Professor Jean Guex, Université de Lausanne, Institut de Géologie et Paléontologie, BFSH 2, Lausanne CH-1015, Switzerland. A more detailed explanation of the theoretical concepts on which the program is based is given by Savary and Guex (1990, 1991) and Guex (1991).

SITE 1

Layer	Artifact										Local Horizon	
	1	2	3	4	5	6	7	8	9	10		
5	1	1						1			{1 2 8}	LMH
4				1	1			1			{4 5 8}	LMH
3							1	1			{7 8}	LMH
2							1		1	1	{7 9 10}	LMH
1							1		1		{7 9}	

SITE 2

Layer	Artifact										Local Horizon
	1	2	3	4	5	6	7	8	9	10	
4	1	1	1								{1 2 3}
3	1	1									{1 2}
2					1	1					{5 6}
1									1	1	{9 10}

SITE 3

Layer	Artifact										Local Horizon
	1	2	3	4	5	6	7	8	9	10	
4				1		1					{4 6}
3						1	1	1			{6 7 8}
2						1	1	1	1		{6 7 8 9}
1									1	1	{9 10}

Fig. 4. The stratigraphic sequences and contents of layers for three fictitious sites.

Superpositional Relationships and Reproducibility

For any two artifacts, only two superpositional relationships can be observed: one where Artifact X is below another, Z, (X ⇒ Z) and another where X is above Z (X ⇐ Z). In graph theory, these relationships would be expressed, respectively, as an arc below and an arc above. Artifact superpositions are determined from the relationships observed at each site.

The determination of superpositional relationships can be problematic when using presence/absence data because, as mentioned, they are particularly susceptible to the effects of artifact intrusions. UAM attempts to counter this problem by recording the *reproducibility* of the observed relationship. A superpositional relationship between two artifacts is said to be reproducible if that same relationship is found at more than one site. Reproducibility is a way of weighting certain relationships. The assumption here is that an observed relationship gains "global" reliability when it is observed at more than one location. The frequencies of reproducibilities are recorded so that X [4] ⇒ Z would indicate that X is found below Z at four sites. The value of reproducibilities is actually the sum of arcs and the number of sites in which that relationship is found. This is because each arc is reproduced at least once (i.e., in at least one site).

The *Biograph* program has the option of calculating the total values of superpositions by using the values of either arcs or reproducibility or the sum of both. The way superposition totals are calculated can have a considerable effect on the ordering of sets. For instance, if only reproducibilities are counted, then we are giving a similar weight to arcs and reproducibilities. If, however, we count both arcs and reproducibilities, then we are actually counting arcs twice and giving more weight to superpositional relationships observed within sites than to those reproduced between sites. In this analysis and in the following case study, only reproducibilities were counted, giving emphasis to relationships observed at two or more sites.

Real and Virtual Associations

When two or more artifacts are found in a firm context, as in the same layer, they are said to share a *real association.* In Fig. 3, Artifacts 7 and 8 are connected by a real association at Layer 3. Often, however, associations can be implied. For example, Artifact 7 was not observed at Layer 2 and Artifact 8 is absent at Layer 4, but because both artifacts were found in the layer above and below, we can infer that they existed for the interval. Such inferred associations are referred to as *virtual associations.* UAM considers virtual associations to be valid and integrates them into analysis. The stratigraphic matrix for Site 1 is modified (Fig. 4) to show two virtual associations, the set {4, 5, 8} at Layer 2 and the set {7, 9, 10} at Layer 4.

Virtual associations are created on the assumption that the archaeological record is accurate as recorded. Admittedly, such an ideal situation rarely exists. Artifact intrusions, reuse, differential deposition, differential preservation, and sampling bias are factors that can affect the apparent existence interval of an artifact. Yet, practically speaking, it is unlikely that, for every site and for every period, all classes of artifacts representative for those sites and periods could ever be recovered. Perfect recovery assumes not only that all representative artifacts were equally deposited and preserved in all horizons but also that all layers associated with these horizons were excavated to their fullest extent. Lacking such evidence, we must assume that the archaeological information at hand is correct and develop a method to account for any contradictions in superpositions (Guex, 1991).

It is relevant that UAM does not obtain results based on the evaluation of individual artifacts, but on sets of associated artifacts. Because we are working with sets and subsets of artifacts, the effects of lengthened existence intervals may produce correlations that are less precise, but the resulting correlations will not necessarily be incorrect. For example, a curated Model T Ford would occur among a very different set of artifacts in 1998 than it would have in 1927, provided that chronologically relevant artifact classes are selected for comparison.

Local and Maximal Horizons

When real and virtual associations have been recorded, *local horizons* are created. A local horizon is simply the set of all associated artifacts in a layer (Fig. 4). A local horizon is an ethnostratigraphic unit that has been defined initially on the basis of a lithostratigraphic unit (the layer). It can be loosely envisioned as a set of artifacts (a site component) that represents an occupation level. As we proceed, the original layer numbers become less appropriate for identifying horizons because we begin to step beyond the initial lithological grouping. Temporarily, however, these numbers are retained for purposes of explanation.

A *local maximal horizon* (LMH) is a local horizon that contains a unique association of artifacts. It is a set of associated artifacts that cannot be subsumed under any larger set. For example, at Site 1, the local horizons formed at Layers 2, 3, 4 and 5 are considered LMHs but note that, at Layer 1, the local horizon of {7, 9} forms a subset of the LMH above it {7, 9, 10}. The unique associations present in a LMH are of particular interest because they serve as chronological markers. Sets that are redundant (as in Layer 1) are not useful for distinguishing distinct intervals of time. The numbers assigned to the LMHs are based on the original layer numbers. In all, 10 LMHs have been created from 14 local horizons (Table I).

Table I. Local Maximal Horizons (LMHs)

Site	LMH	Artifact Set			
1	5	1	2	8	
	4	4	5	8	
	3	7	8		
	2	7	9	10	
2	4	1	2	3	
	2	5	6		
	1	9	10		
3	4	4	6		
	2	6	7	8	9
	1	9	10		

Table II. Residual Maximal Horizons (RMHs)

RMH	Site.Layer	Artifact Set			
1	3.2	6	7	8	9
2	2.4	1	2	3	
3	1.5	1	2	8	
4	1.4	4	5	8	
5	1.2	7	9	10	
6	3.4	4	6		
7	2.2	5	6		

Maximal horizons can themselves become redundant. We may find, for instance, that one maximal horizon from one site forms a subset of a maximal horizon from another. Redundant maximal horizons are merged with their respective larger sets, and these remaining sets are called *residual maximal horizons* (RMHs). For example, among all sites, the 10 LMHs can be reduced to 7 RMHs (Table II). RMHs retain all information about the artifact associations observed in all sites.

Neighborhoods

For each artifact (in all sites), we record its individual associations. The set of artifacts associated with any artifact, X, is said to form the *neighborhood* of X (Guex, 1991, p. 15). For example, if Artifact X is associated at one site with Artifact W, at another site with Artifact Y, and at yet another with Artifact Z, then the neighborhood of X is [W, Y, Z]. It is important to note that while X was found in association with these three artifacts, this does not imply that any of W, Y, or Z were found in association. Neighborhoods are artifact specific, not sets of associated artifacts.

Maximal Cliques

Residual maximal horizons are used in conjunction with neighborhoods to create enlarged sets called *maximal cliques* (MCs) (Guex, 1991, p. 37). Artifacts are added to an RMH when certain conditions are satisfied. The principle is transitive. Assume, for example, that Artifact 1 is associated with Artifact 4 at Site A and with Artifact 7 at Site B. If, at another site, C, Artifacts 4 and 7 are found in association, then we can deduce that all artifacts (1, 4, and 7) are contemporary, whether or not their actual association is ever observed. In other words, if we have three sets of associated artifacts, {1, 4}, {1, 7}, and {4, 7}, then it follows that 1, 4, and 7 are all associated.

To create MCs, the RMHs are compared to the neighborhoods of artifacts. If any RMH forms a subset of any neighborhood, then the artifact with which that neighborhood is identified is added to the RMH, creating an MC. For example, consider RMH 4 and its set of associated artifacts, {4, 5, 8} (Table II). Compare this set to the neighborhoods listed in Table III. We see that RMH 4 forms a subset of the Artifact 6 neighborhood. This means that, because all elements of RMH 4 are associated with Artifact 6, then Artifact 6 is associated with all artifacts in RMH 4. By deduction we may add Artifact 6 to RMH 4 and, in the process, create a new set of associated artifacts, {4, 5, 6, 8}. This enlarged set is called an MC (MC 1 in Table IV).

RMHs 6 and 7 can be enlarged in the same way, creating sets {4, 5, 6} and {5, 6, 8}, respectively. But these enlarged sets are not unique because they both form subsets of the newly created MC 1, {4, 5, 6, 8}. Consequently, these two sets are merged with MC 1; this process creates five maximal cliques.

To summarize the procedures thus far, local horizons are initially defined at each site on the basis of lithological context, and the artifacts contained within each context become elements in a set of artifacts (the local horizon). At each site, those local horizons containing redundant sets are eliminated, or merged, to leave only LMHs. LMHs are then compared between sites, and, once again, any redundant sets (subsets) are merged with their respective greater sets. The remaining maximal horizons are called RMHs. RMHs are then compared to artifact neighborhoods and, if any RMH forms a subset of an artifact's neighborhood, then that artifact is added to the subsumed RMH. The remaining and enlarged RMHs are called MCs.

Table III. The Neighborhoods of Artifacts

Artifact *N*:	Neighborhood						
1:	2	3	8				
2:	1	3	8				
3:	1	2					
4:	5	6	8				
5:	4	6	8				
6:	4	5	7	8	9		
7:	6	8	9	10			
8:	1	2	4	5	6	7	9
9:	7	8	10				
10:	7	9					

Table IV. Maximal Cliques (MCs)

MC	Site.Layer	Artifact Set			
1	1.4[a]	4	5	6	8
2	3.2	6	7	8	9
3	1.5	1	2	8	
4	2.4	1	2	3	
5	1.2	7	9	10	

[a] This MC contains RMHs 4, 6, and 7 (Table II).

MCs are ethnostratigraphic units representing unique associations of artifacts for all sites being examined, but they are not yet ordered in time. Up to this point we have observed only associational relationships among artifacts, not superpositional relationships. The MCs now need to be ordered on the basis of artifact superpositions.

Superpositions of MCs

Artifact superpositions and the reproducibility of these superpositions are determined from observations at each site (Table V). In Table V, all relationships are shown as being unidirectional so that the identified artifact (on the left) is superpositionally below those listed to its immediate right. The number of times any relationship is reproduced is shown in brackets. For example, Artifact 1 is found above Artifact 5 at two [2] sites.

Table V. Superpositional Relationships

Artifact N:	Artifacts above *N* and [reproducibility]						
1:							
2:							
3:							
4:	1 [1][a]	2 [1]					
5:	1 [2]	2 [2]	3 [1]				
6:	1 [1]	2 [1]	3 [1]				
7:	1 [1]	2 [1]	4 [2]	5 [1]			
8:							
9:	1 [2]	2 [2]	3 [1]	4 [2]	5 [2]		
10:	1 [2]	2 [2]	3 [1]	4 [2]	5 [2]	6 [2]	8 [2]

[a] Artifact 1 is above artifact 4 at only one [1] site.

The stratigraphic relationships between MCs are determined by the sum of the relationships of the artifacts they contain. There are three possible relationships between any two MCs, MC 1 and MC 2 (Guex, 1991, p. 81).

1. Superpositional: If an artifact of one MC, MC 1, is above (or below) any artifact of another MC, MC 2, then MC 1 is above (or below) MC 2.
2. Undetermined: If none of the artifacts of MC 1 are associated with those of MC 2 and the superpositional relationship between artifacts is undetermined, then the relationship between MC 1 and MC 2 is undetermined.
3. Conflicting: If contradictions and cycles occur among artifacts, these need to be resolved.

The Resolution of Contradictions and Cycles

A conflicting relationship occurs when one or more artifacts are found both above and below other artifacts. A *contradiction* is a conflicting relationship that occurs between *two artifact types* when one artifact is found both above and below the other. A *cycle* is another kind of relational conflict that occurs among *three or more artifacts.* For example, a cycle would occur when X is above Y, Y is above Z, and yet Z is above X. Cycles can be quite complex and can involve any number of artifacts. When cycles occur among sets of artifacts (MCs), the related sets are called *strongly connected components.* The conflicting relationships among strongly connected components need to be eliminated before completing the analysis. This is accomplished by identifying and eliminating the most problematic contradictions one at a time until the cycle is resolved. In most cases, a strongly connected component involving many artifacts can be resolved with the elimination of a small number of contradictions. The objective of analysis is to eliminate as few relationships as possible in order to preserve superpositional information.

The *Biograph* program uses a simple technique to resolve contradictions and determine the superpositional relationships between MCs. The relationship between any two cliques is solved by calculating the number of superpositions and their reproducibilities. There are two underlying assumptions: (1) that, among all sites, Artifact X is considered to be above (later than) Artifact Y if it is found above Y more often than it is below Y and (2) that this relationship is strengthened if it is found to be true at more than one site.

When Artifact X is above Artifact Y, the relationship is expressed as $X \Leftarrow Y$ (an arc above), and when Artifact X is below Artifact Y, it is expressed as $X \Rightarrow Y$ (an arc below). The reproducibility of $X \Leftarrow Y$ is represented as "RA" and, for $X \Rightarrow Y$, as "RB."

The calculation of superposition is as follows: For any pair of MCs, MC 1 and MC 2, total the $X \Leftarrow Y$ and the $X \Rightarrow Y$ relative to any one clique. In addition, total the number of reproducibilities for each superpositional relationship. The relative position of each MC, MC 1, to every other MC, MC 2, is determined by calculating the following values (Guex, 1991, p. 81):

$$\text{Value above (VA)} = \text{sum of } X \Leftarrow Y + \text{sum of RA}$$

$$\text{Value below (VB)} = \text{sum of } X \Rightarrow Y + \text{sum of RB}$$

Then the following determinations are made.

If VA > VB, then MC 1 is above MC 2.
If VA < VB, then MC 1 is below MC 2.
If VA = VB, then the relationship is undetermined.

This procedure is followed for all MCs. It resolves contradictions and determines superpositional relationships on the basis of observed relationships. During this process, cycles are detected and eliminated. As an example, consider the possibility that the cycle MC 1 $\Rightarrow$ MC 2 $\Rightarrow$ MC 3 $\Rightarrow$ MC 1 occurs. To resolve this cycle, it is necessary to return to the VA and VB values calculated above. For each pair of MCs, we compare the values of VA and VB, take the minimum value (this could be either VA or VB), and divide it by the maximum value. This creates a coefficient where the highest possible value is 1. A value of 1 indicates that the relationship between two MCs is undetermined because there is an equal number of opposing superpositions. The highest coefficient values will, therefore, identify the most problematic relationships occurring within a cycle. The formula is

$$f(A) = \min [VA, VB]/\max [VA, VB])$$

where $f(A)$ = is the coefficient.

In a three-point (three-MC) cycle, eliminating one contradiction will eliminate the cycle. Where more than three points are involved, the cycle could persist, and if so, the operation is repeated. In this way, it is possible to retain the maximum number of superpositional relationships by removing only the most problematic relationships one at a time. If, as a result of this operation, any two cliques have an undetermined relationship, it does not imply that these cliques cannot be ordered. They still retain determined relationships with all other cliques.

The UAM of determining superpositions may seem too deterministic. But the interested reader can access the actual coefficient values under a class of subroutines referred to as BG Tools. In this particular case, the subroutine is BG_T09, which identifies coefficient values as $f(A)$ that can be used to judge specific relationships.

The results of analysis can be no better than the input data. Excavation samples are generally incomplete and contradictions naturally occur, but if heavily disturbed sediments are defined as lithological units, higher numbers of cycles and contradictions will result and the possibility of making poor determinations increases. In these situations, it is less likely that any technique will resolve the stratigraphic sequence once out of the field. One possible remedy is to identify problematic associations and, therefore, problematic deposits, by conducting a stepwise analysis of excavation areas *within* the site, a topic discussed at the end of this section.

Unitary Associations

Returning to our example, the unsorted MCs shown in Table IV are now ordered in the manner described above and reentered in matrix form (Fig. 5A). The original MC numbers from Table IV are used. Once ordered, we see that new existence and concurrent intervals are created for certain artifacts. Virtual associations are again added and new associated sets of artifacts created (Fig. 5B). Notice that new redundancies occur and MC 3 becomes a subset of MC 4. The sorted and residual MCs are renumbered from the bottom up (Fig. 5C). These are what Guex (1991, p. 15) calls *unitary associations* (UAs). UAs are ethnostratigraphic units created using interval ethnozones.

A

No.	Artifact										Maximal Clique
	1	2	3	4	5	6	7	8	9	10	
3	1	1						1			{1 2 8}
4	1	1	1					0			{1 2 3}
1				1	1	1		1			{4 5 6 8}
2						1	1	1	1		{6 7 8 9}
5							1		1	1	{7 9 10}

B

No.	Artifact										Maximal Clique
	1	2	3	4	5	6	7	8	9	10	
3	1	1						1			{1 2 8}
4	1	1	1					1			{1 2 3 8}
1				1	1	1		1			{4 5 6 8}
2						1	1	1	1		{6 7 8 9}
5							1		1	1	{7 9 10}

C

No.	Artifact										Unitary Association
	1	2	3	4	5	6	7	8	9	10	
4	1	1	1					1			{1 2 3 8}
3				1	1	1		1			{4 5 6 8}
2						1	1	1	1		{6 7 8 9}
1							1		1	1	{7 9 10}

Fig. 5. Unitary associations are formed by ordering maximal cliques (A), creating virtual associations (B), and, finally, merging subsets and renumbering the remaining sets (C).

Correlation of Strata

The UAs now provide a reference against which the contents of all layers (local horizons) can be compared. The final step in analysis is to assign each local horizon from each site to one of the sorted UAs. This is done by assigning the local horizon to the range of UAs of which it forms a subset (Fig. 6). At Site 1: for example, the local horizon contained in Layer 5 is {1, 2, 8} (Fig. 4). This horizon forms a subset of UA 4 {1, 2, 3, 8} (Fig. 5C) and is, therefore,

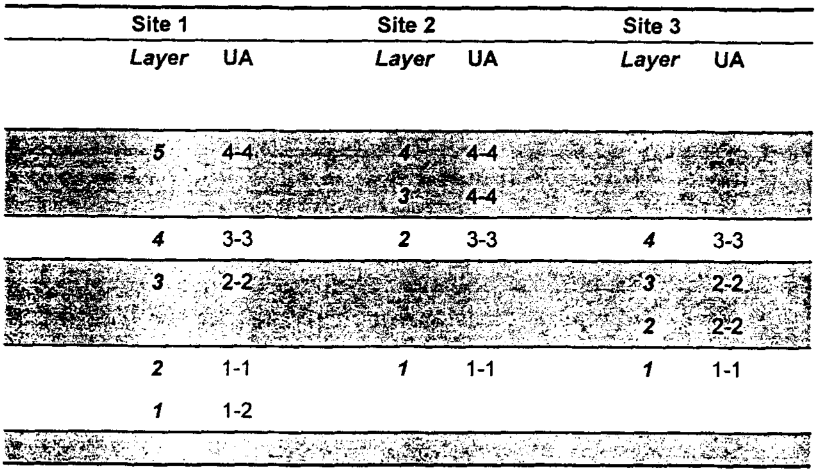

Fig. 6. The correlation of layers among the three fictitious sites.

assigned to UA 4. In Fig. 6, the UA membership of Site 1/Layer 5 is given as 4–4. This means that Layer 5 is a member of UA 4 only. Compare this to Site 1/Layer 1, where the membership is given as 1–2. This means that Layer 1 could be a member of either UA 1 or UA 2. This situation occurs because the composition of the local horizon is such that no firmer placement can be obtained. Nonetheless, situating the layer is not a problem because we know that Layer 1 occurs stratigraphically below Layer 2. As Layer 2 is a member of UA 1, then we must conclude that Layer 1 is also a member of UA 1. When a layer is assigned to more than one UA, like Layer 1, it does *not* suggest the presence of site disturbances or intrusions of any kind. These factors have already been accounted for in the resolution of contradictions and cycles. It merely reflects the indeterminate nature of the artifact sample, as defined by the local horizon, and can result from small sample size at the site. The correlated layers at these three sites now comprise a regional ethnostratigraphic unit, which, by definition, would be an ethnochronozone.

Discussion

The demonstration of the method was intended to highlight the operational principles of UAM. The data, demonstration, and results are idealized. In most practical applications, the data need to be carefully evaluated and the results thoughtfully interpreted. Experience has demonstrated that good results are not obtained by simply throwing hundreds of artifact classes into analysis.

The necessary first steps are to create an artifact typology, define deposits as lithostratigraphic units, assign artifacts to deposits, and construct a sequence of these deposits for each site. A Harris (1975, 1989) matrix works well for constructing the sequence and computer programs are available to facilitate the process (e.g., Scollar *et al*, 1997). The initial preparation of data cannot be overemphasized because the accuracy of results is directly linked to the degree that artifact associations represent true contemporary associations. The validity of any association must be determined in the field, a fact that underscores the need for geoarchaeological analyses of contexts and rigorous methods of stratigraphic control.

A sequence of UAs is a chronological sequence of sets of artifact classes that are unique in their composition. If the data used are pottery types, then the UAs represent a sequence of pottery classes and define periods of time in terms of those classes. Different classification systems will produce different associations and may order MCs in a different way. A chronology based on lithic material will usually yield different results because changes in lithic classes do not always coincide with changes in pottery styles. One advantage of UAM is that different classes of materials, such as pottery, lithics, and architectural features, can conceivably be combined in analysis, and doing so may give more meaningful results. In any case, the choice of variables will inevitably condition the results.

In general, the best results are obtained when the artifact classes used are present at two or more sites, but this is not always the case. An artifact that occurs at only one site (not layer) is an *unmatched artifact.* Unmatched artifacts can have a considerable effect on correlations because of the way in which UAM calculates superpositions. For example, if, at each site, an artifact occurs only in the bottom layer, then every other artifact that is not a member of its local horizon must appear above it. Alternatively, when an artifact is in the top layer, then every other artifact that is not a member of its local horizon must appear below it. The calculation of superpositions is, therefore, subject to *boundary effects,* and the degree of this effect is in direct relation to the number of artifacts above and below the unmatched artifact (Fig. 7). When unmatched artifacts are left in the analysis, they affect the order of MCs by either "pushing" them up or "pulling" them down so that associations appear too old or too young, respectively. Because superpositions are based on observations at the site level, the layers most affected by this process are those on the upper or lower ends of the stratigraphic sequence. Boundary effects apply to matched artifact types as well as unmatched, but the effects of matched types are usually countered by the relationships occurring at other sites.

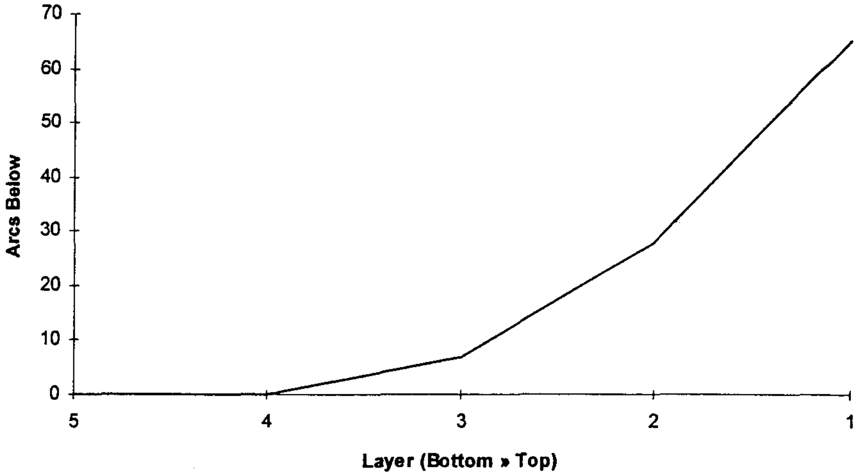

Fig. 7. Superpositional relationships of maximal cliques are affected by the stratigraphic position of unmatched artifacts. A simulation demonstrates the total number of "arcs below" created by one unmatched artifact in the bottom layer (Layer 5) of a five-layer site that contains a random chronological distribution of 100 artifact types. The number of arcs below is a function of the stratigraphic distance.

There are times when the inclusion of unmatched artifacts is desirable. For instance, a layer at one site may contain a local horizon that represents a unique occupation period (i.e., not represented at other sites). In this case, if we remove all unmatched artifacts, the local horizon loses its unique composition and, instead, is correlated on the basis of the few remaining artifacts it shares with other sites. If the remaining shared artifacts are the same as those of an earlier period at another site (which is possible if we are dealing with homologous assemblages), the effect will be to pull the timing of this occupation down to the "level" of the earlier period. As a general rule, it is better to avoid unmatched artifacts and unique local horizons. Removing unmatched artifact types from a chronological analysis does not prevent a reconsideration of these same artifacts in any subsequent synchronic analyses of, for example, regional trade or political control.

A factor affecting chronological resolution is the variable length of existence intervals; that is, the length of time represented between an artifact's first and its last appearance in a reliable stratigraphic context. Those classes of materials that span the whole sequence (i.e., all UAs) are not useful for distinguishing unique sets of artifacts and, ideally, should be removed from analysis. This is something that usually cannot be done until the initial analysis is complete because it is only at this point that we know the ordering of

UAs. In practice, however, I have found that removing these classes from analysis has little or no effect on the order of MCs, although it does tend to create a greater number of UAs. This occurs because, once the full-range artifact types are removed, all horizons become more unique in composition.

AN APPLICATION OF METHOD IN THE SOUTHERN LEVANT

The *Biograph Version 2.02* program was used to order ceramic data from four archaeological sites in the southern Levant (Fig. 8): Ai, Arad, Jericho, and Far'ah North (Callaway, 1972, 1980; Amiran, 1978; Kenyon and Holland, 1982, 1983; de Vaux and Steve, 1948; de Vaux, 1955, 1961). The periods of occupation included in this analysis range from the latter part of the Late Neolithic (ca. 5000–4500 cal BC) to the Early Bronze 3 (2700–2300 cal BC).

Site Stratigraphy

Ethnostratigraphic units should be defined on the basis of individual deposits and we often assume that this is the case in site reports. In many cases, however, not enough information is published to verify the excavator's conclusions. For this analysis, the best reported sites, in terms of stratigraphy and content, are Jericho, Ai, and Arad, respectively. Section drawings or stratigraphic sequences are reported at Jericho and Ai only, although there are a few section drawings of probes and one excavation unit at Arad (Amiran and Ilan, 1996). Despite the good reporting at Jericho, it has been demonstrated that the excavator's phasing of the deposits does not entirely conform to their stratigraphic sequence (Triggs, 1993). Therefore, it is with some reservation that, in each individual case, the excavators' phasing is accepted as given.

The chronological scheme for the periods represented here is, in general, well-known to those familiar with the archaeology of the southern Levant, and in some respects, the results of the analysis appear trivial. However, it should be remembered that it is the excavators' phases (ethnostratigraphic units) that are being used to determine associations rather than individual deposits (lithostratigraphic units). By accepting these phases as groups of associated artifacts, there is always the danger of creating groups or associations that are not contemporaneous in their entirety. Only at Jericho and Ai (and maybe Arad) is it possible to define smaller deposits on the information given in site reports. Nonetheless, because these phases have been created using a common pool of diagnostic artifacts, they are useful for a demonstration of UAM on archaeological data. It is possible to use this sequence as a control and, consequently, to illustrate some of the strengths and weaknesses of the method.

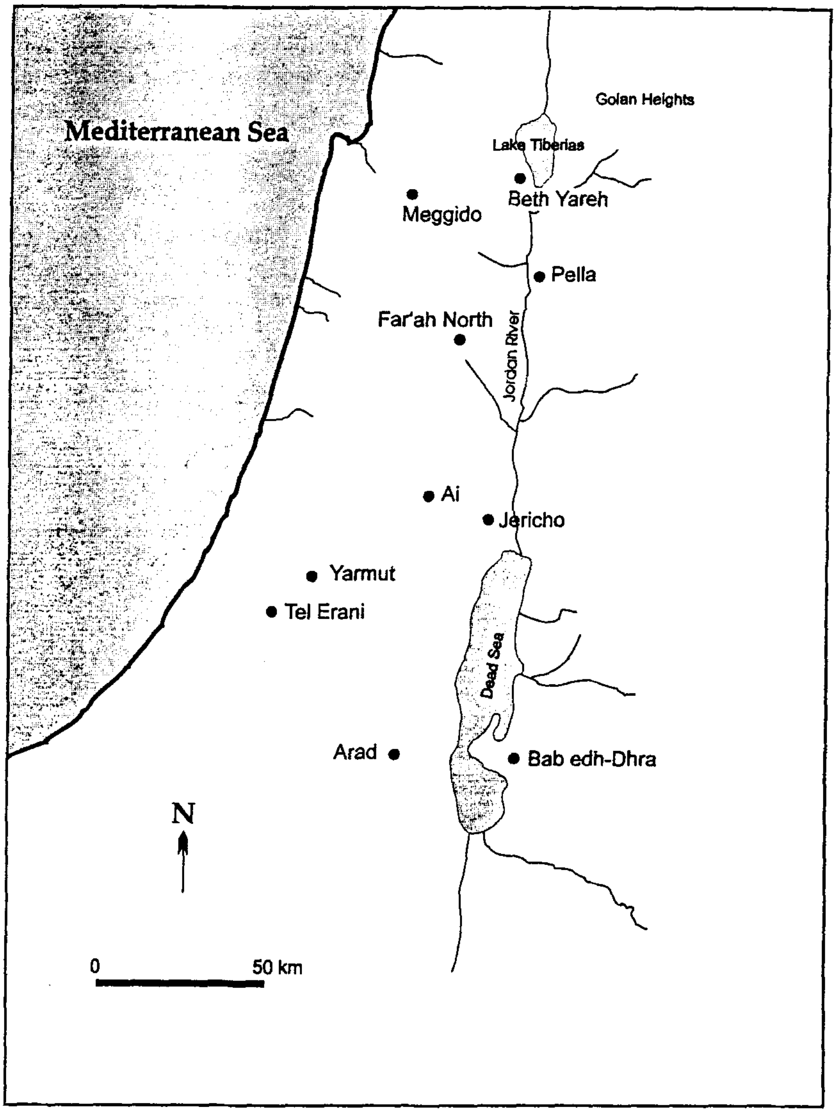

Fig. 8. Map of the southern Levant.

At Jericho, the stratigraphic units are called "stages" and "phases." In Kenyon and Holland's (1982, 1983) terminology, a stage is defined on its upper and lower limits by major construction events. Jericho covers a sequence that ranges both above and below the Stages 31–41 used here, which are those covering periods from the Late Neolithic (Pottery Neolithic B), through the Chalcolithic (4500–3500 cal BC), and up to the Early Bronze 3. This is the longest sequence of all four sites.

At Ai, the stratigraphy is defined in terms of "phases" and "strata." Unlike Kenyon and Holland, Callaway (1972) uses the term "Phase" to represent periods between construction events, while strata designate smaller deposits. Phases at Ai are synonymous with Jericho's building stages. The sequence at Ai spans Phases 1 to 7 at Site A (the Sanctuary). These phases are numbered from the bottom up and range from Early Bronze Age 1b to Early Bronze 3.

The stratigraphic units at Arad are called "strata." Amiran (1978) is not explicit about how stratigraphic units are defined at Arad, but the discussions and plans from the site report imply that a stratum is defined on its upper and lower limits by construction events and is composed of a number of smaller deposits. The sequence at Arad ranges from Stratum 5 to Stratum 1. They are numbered from the top down and span from the Chalcolithic to Early Bronze 2.

At Far'ah North, occupation levels are referred to as "periods." These, too, appear to be defined on their upper and lower limits by construction activity. In de Vaux's terminology, these periods span the time from the Middle Chalcolithic (which is now generally regarded as Late Neolithic) to the Late Bronze Age. The periods used in this analysis are those ranging from the *Chalcolithique Moyen* (Middle Chalcolithic) to the *Chalcolithique Superieur* (Upper Chalcolithic) and through a sequence of five periods of the *Ancien Bronze* (Early Bronze Age). The phasing terminology for this site has been revised (Chambon, 1993) and this revised sequence is used here; later phases have been excavated but are not used in this analysis.

For the sake of consistency, the ethnostratigraphic units at each site are referred to as "strata." Each stratum has been numbered as the excavator numbered them, with the exception that Roman numerals are not used. In all, there are 29 strata at four sites, creating 29 local horizons.

Taxa

The taxa used in analysis consist of both pottery types and attributes. It was not possible for the writer to conduct a hands-on examination of all ceramic material from these sites. Instead, a classification system was devised to take advantage of pottery profiles and descriptions in site reports.

Very little of the comparative material consists of whole vessels, and consequently, classification is limited mainly to rim sherds and diagnostic features of form and decoration. The criteria used for classification are based on discussions of changing pottery forms and styles for the periods in question (e.g., Hennessy, 1967; Amiran, 1969, 1985; Callaway, 1972, 1980; Hanbury-Tenison, 1986; Stager, 1992)

A classification system was devised to create both superclasses and subclasses of pottery. Subclasses were created on the basis of nominal and interval scale variables, including rim diameter, form, rim lip type, and decoration type, while superclasses were defined on combinations of these subclasses. By using only subclasses in analysis, it is possible to miss important combinations of attributes; alternatively, use of only superclasses risks loss of information that also may be chronologically relevant. For example, a common pottery type in the southern Levant for the period investigated is a "hole-mouthed jar." This jar can be identified primarily by its form but was manufactured with several rim lip designs and different kinds of appliqué (e.g., "rope" moldings). If we create three subclasses, where "A" represents form and diameter, "B" represents lip design, and "C" defines the decoration, then the superclass is named "ABC." Yet the possibility exists that holemouth jars with rope moldings appear *at all sites* at a specific time, regardless of the rim lip design. To overcome this potential problem, and to retain as much information as possible, each superclass is used to create every possible combination of subclasses. Using our example, pot ABC is divided into the set {ABC, AB, AC, BC, A, B, C}, which represents the pot in all combinations of attributes.

Two concerns arise in using this typological scheme. First, it is conceivable that this method of classification would create unwieldy numbers of classes. But, in practice, it seldom does. We are using only presence/absence data so each horizon contains only one representation of each class. If four pots found in one local horizon have rope moldings, the rope molding attribute is entered only once for that horizon. Furthermore, it is often the case that many combinations will be unmatched. In this analysis, 124 comparable artifact classes were created. Second, this typological scheme has the effect of entering one artifact as several types and it could be claimed that the types created are not mutually exclusive because the associations of attributes are created from a single entity. But the associations themselves are mutually exclusive. Admittedly, the types are not entirely independent because they are based on sherds rather than whole pots. Nonetheless, a number of analyses, each using different methods of classification, demonstrated that this technique improved correlations.

ANALYSIS AND RESULTS

The data were prepared and entered as a text file (ASCII format) for the *Biograph* program. Artifact types are assigned to a numbered and sequenced stratum in each particular site. Based on this information, the following summary of results was produced in the report file (*.rep):

29 Local horizons
26 RMHs
23 MCs
12 UAs
218 Contradictions
2 Strongly connected components
11 Vertices (MCs) in strong components

The original 29 local horizons were reduced to 26 RMHs. Of these, 19 were enlarged on the basis of object associations (using neighborhoods), producing 23 MCs. The number of MCs is three less than the number of RMHs because two other sets became subsets of the enlarged MCs.

The superposition of the MCs is calculated on the superpositions of artifacts. In this case, we have 124 artifacts in 23 MCs, among which 36,475 arcs are observed. Of these, 4698 arcs are contradictory, which amounts to 13% of all arcs. Because there are 23 MCs, there are 253 comparisons of superpositional relationships to be made among them. Out of all comparisons, 218 contain some contradictions. Once resolved, there are only two MCs with undetermined relationships. At what point the number of contradictions becomes a serious problem has not yet been adequately explored. A bootstrapping method (Kvamme *et al.,* 1996) using about 100 iterations may produce good results, as well as permitting the calculation of standard errors and confidence intervals. Guex (1991, p. 60) notes that an analysis of 100 taxa can produce several thousand contradictions and still give good results.

In addition to contradictions, there are two strongly connected components; that is, there are two groups of MCs among which cycles occur. In the first group, there are 13 MCs involved in the cycle, while in the second, there are only 3. By the time both cycles and contradictions are resolved, there are 16 undetermined relationships (of a possible 253) among all MCs. This is not necessarily a problem because MCs with undetermined relationships can still be ordered on the basis of their relationships with other MCs.

Unitary Associations				Excavator's Terms				
Arad	Far'ah N	Ai	Jericho	Arad	Far'ah	Ai	Jericho	*Period*
		7: 5 - 12	41: 8 - 12			EB 3b	EB 3	
		6: 12 - 12	40: 8 - 12			EB 3a	EB 3	*EB 3*
		5: 12 - 12	39: 12 - 12			EB 2b	EB 3	
	5: 11 - 11	4: 11 - 11			EB 2	EB 2a		
1: 7 - 10				EB 2				
2: 10 - 10			38: 10 - 10	EB 2			EB 2	
	4: 8 - 9				EB 2			*EB 2*
	3: 8 - 9				EB 2			
	2: 9 - 9				EB 2			
3: 8 - 8				EB 2				
	1: 7 - 7				EB 2			
		3: 6 - 6				EB 1c		
		2: 6 - 7	37: 6 - 6			EB 1b	EB 1	*EB 1b*
4: 5 - 5		1: 5 - 9		EB 1b		EB 1b		
			36: 4 - 4					
			35: 4 - 4				PU/EB 1	*EB 1*
	S: 3 - 3		34: 3 - 4		EB 1			
5: 2 - 2				Chalc				*Chalc*
	M: 1 - 1		32: 1 - 1		Chalc		PNB	
			31: 1 - 1					*LNeo*

Fig. 9. Left: The strata at each site are associated with particular UAs (see text). The format 7: 5-12 means that strata 7 forms a subset of UAs 5 to 12. Right: The periods assigned by the excavators [with the exception of Tell Far'ah North, where Chambon's (1993) phasing is used]. The column at the far right suggests period groupings. CM, Chalcolithique Moyen; CS, Chalcolithique Superieur; Chalc, Chalcolithic; LNeo, Late Neolithic; EB, Early Bronze Age; PU, Proto Urban.

This procedure creates an ordering of MCs to which virtual associations are added and the resulting sets merged where possible. In the final analysis, there are 15 UAs. At this point, we return to the local horizons, and place these into those UAs of which they form a subset. The results are shown in Fig. 9. The format of 7: 5-12 (e.g., at Ai) means that the local horizon belonging to Stratum 7 at the site of Ai forms a subset of UAs 5 to 12. This wide range is usually an indicator that there are too few artifacts in this horizon to permit a firmer placement. Nonetheless, Stratum 7 must belong to UA 12 because it is above Stratum 6, which is itself firmly positioned in UA 12.

The situation at Ai, Stratum 1 is a little different. This stratum can be associated with UAs 5 to 9 but we see that, on its upper limit, it is confined by Stratum 2, which belongs to UA 6. This means that Stratum 1 is situated between UA 5 and UA 6 but cannot be more firmly placed.

The periods assigned to each stratum by the excavators are shown on the right in Fig. 9 and the general groupings of strata are shown under the "Period" column. In general, the results of analysis tend to confirm the existing chronological framework but suggest that finer chronological subdivisions are possible. The results obtained here do not necessarily agree on all points with the sequence as known because not all stratigraphic information for the region has been integrated into analysis. For example, in light of the published sequence from Umm Hammad (Helms, 1984, 1986, 1992), it is likely that the EB 1 period at Tell

Far'ah North will be "pushed up" above the Jericho Proto Urban (PU) phase as Hanbury-Tenison (1986, p. 128) has suggested. Also, the assignment of Ai, Stratum 5 (EB 2a), to the EB 3 could be disputed. Once again, additional information from other sites can help to clarify the matter.

The ordering of UAs tells us nothing about the duration of each UA or the span of time between UAs. This is a relative sequence of events. For example, at Ai, there appears to be a considerable gap between EB 1c and EB 2a, but this gap may represent a very short period of time. Alternatively, there appears to be no gap between the Chalcolithic and the EB 1 levels, although it is possible that the intervening period spans hundreds of years. Only absolute or time placement dates can offer the reference points needed to estimate the length of intervals.

CONCLUSION

UAs are ethnozones that, when applied across a region, become ethnochronozones. The term "Early Bronze Age" could loosely be defined as an ethnochronozone because it relatively dates regional sites on the basis of their contents and assumes upper and lower chronological limits. The objective of further analyses should be to reduce the diachroneity of boundaries, therefore creating ethnochronozones of shorter duration. This can be done by using smaller lithostratigraphic units for defining horizons, plotting the sequence of these deposits, and creating more detailed typologies. In most cases, this can be accomplished independently using site reports, provided that site stratification and related archaeological materials have been well documented. Creating ethnochronozones, or periods, of shorter duration will make it possible to conduct more detailed analyses of settlement patterns and interactions between communities. Once accomplished, we will be in a better position to explain significant changes throughout a region for the period investigated. In the case of the southern Levant, the demise of Chalcolithic period settlements just before the onset of the EB 1 and the rise of urban communities during the EB 2 period are of particular interest to many researchers.

The results of UAM would be enhanced by the application of statistical procedures to establish confidence intervals for the superpositional relationships of MCs. Although computationally complex, bootstrapping methods can be used to derive error terms for the ordering obtained (e.g., Lipo and Madsen, 1997). In a similar manner, those artifact types that account for the greatest variability in ordering can be identified, and their classifications and contexts reevaluated. Once the sequence of UAs is known, several statistical procedures applicable to ordinal-scale measurements can be used. For example, changes in assemblages over time can be evaluated using Mann–Whitney and Smirnov tests as well as ANOVA with ranks.

It is clear that good results rely heavily on the recognition and elimination of problems relating to stratigraphic context. Such problems are hardly new to the discipline of archaeology, and it is unlikely that any existing relative chronology could have escaped the challenge of determining both superpositions and contemporary associations. But the UAM may be a little too deterministic in some aspects. Archaeological contexts are seldom clear-cut and our faith in the associations and superpositions of artifacts varies with the amount of stratigraphic information available. For this reason, some method should be devised to assign weights to various contexts. For instance, a value ranging from 0.1 to 1.0 could be used to quantify qualitative assessments of context ranging, for instance, from a poor context to a sealed context. This can be done with the present program by entering the same artifact type two or more times under different type names, but the procedure is cumbersome. A context value added to each artifact type could be used to generate statistics on the observed relationships and to construct confidence intervals, although integrating statistical procedures would require considerable rewriting of the program.

UAM can also be used to correlate layers from noncontiguous areas within a single site. To do this, each excavation area at the site is treated as an individual unit of analysis and each deposit within the area becomes a local horizon. The procedure is useful at any site where excavation areas are separated to the degree that a correlation of layers cannot be achieved on observations of lithostratigraphy alone or where multilinear sequences occur (cf. Harris, 1984). The procedure is also useful for detecting areas of site disturbance. The *Biograph* program reports the number of contradictions and cycles that occur during analysis, and by using a series of subroutines (called BG Tools), the specific artifacts that are most problematic can be located. If the analysis of areas is done in a stepwise fashion, that is, if all combinations of areas are treated systematically, those artifacts that contribute most to the number of contradictions and cycles can be identified.

Like all archaeological methods, UAM is not a stand-alone procedure. There are times when seriation will be the best way to determine the ordering of deposits within a site, and the ordering can then be used to create local horizons for comparing components between sites. The integration of radiocarbon dates (or other time placement dates) into a relative chronological scheme would be beneficial, as MacNeish (1970) demonstrated in his chronological analysis of the Tehuacán Valley. The radiocarbon dates available for each local horizon can be used to check the validity of the sequence produced by UAM. Conversely, the precision of radiocarbon dates can be improved by using stratigraphic information to set prior probabilities in a Bayesian formula (Buck *et al.,* 1991, 1994, 1996).

The *Biograph* program works well and seldom gives any problems in a DOS computer environment, but it is a specialized program that requires the user to be familiar with related publications and to have some knowledge of graph theory. The assumptions of the method are explicit and its computations are deterministic. The quality of results, like all analyses, is directly related to the quality of the input data and some deliberation is required when selecting artifact classes and judging the reliability of archaeological contexts.

If we are to test hypotheses about settlement systems, demographic change, and regional interactions as either causes or consequences of sociopolitical change, then we need to improve regional relative dating techniques. Time placement dates are useful for determining approximate time intervals but they are seldom reliable as a cross-dating technique when used without reference to artifact associations or stratigraphic context. UAM provides a regional framework that allows for the integration of chronometric techniques and prepares a foundation for the improvement of regional dating methods.

ACKNOWLEDGMENTS

I am particularly grateful to Professors Jean Guex and Jean Savary of the Université de Lausanne, Institut de Géologie et Paléontologie, for permitting me to use a copy of their computer program, *Biograph*. Professor Guex's ongoing assistance and advice have proved invaluable to my understanding of the principles of method. Any errors or misrepresentations of UAM particulars are solely my own. I would also like to thank Ted Banning, James Barrett, Jeffrey Dean, William Dever, Reid Ferring, Edward Harris, Jack Holladay, Thomas Levy, Michael Schiffer, Julie Stein, and Patricia Urban for their thoughtful comments on early drafts of this paper.

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